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Technical Report
Reference 97-2
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Approved for Distribution Margaret Leinen

This research program has been funded by the Office of Naval Research under grant number N0000149610356.

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We thank the Captains and crews of the RV ENDEAVOR and RV WECOMA for their assistance in the deployment and recovery of the COOL floats. Sandy Fontana, Jay Rajamony, Paula Perez-Brunius, Peter Lazarevich, Jeff Book and Tom Orvosh are acknowledge for their assistance on the RV ENDEAVOR cruise. Dr. Jim Moum of Oregon State University graciously allowed us to participate on his RV WECOMA cruise and deploy our float twice. This work was supported by ONR Grant N0000149610356.

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Introduction

The goal of this project is to develop a truly three-dimensional Lagrangian follower of water parcels for the coastal ocean. This COastal Ocean Lagrangian (COOL) float is based on an isopycnal float which would follow fluid parcels on a constant density surface. However, in the coastal ocean, there is significant mixing occurring such that a water parcel can change its density over a relatively short time. To account for this effect, we have designed a float which measures vertical (diapycnal, if the float is isopycnal) velocity past it. The COOL float has the capability to change its volume, hence its density, and follow the water parcel.

We have completed two short cruises to test the COOL float. The first one (July 1997) was just off the continental shelf south of Rhode Island. We did six deployments of the COOL float using a variety of vane angles and either as an isobaric or isopycnal float (Table 1). During August 1997, we completed two deployments of an isopycnal COOL float off the coast of Oregon (Table 1) in an attempt to look at water that might be upwelling there.

COOL Float	Type	Vane Angle	Launched Time (UTC)	Launched Position	Recovered Time (UTC)	Recovered Position
3	isopycnal	15°	11 July / 0217	39°49.97'N, 71°18.11'W	11 July / 0815	39°50.44'N, 71°17.95'W
2	isopycnal	90°	11 July / 1303	39°49.85'N, 71°18.02'W	12 July / 0040	39°49.80'N, 71°17.43'W
4	isobaric	15°	12 July / 0205	39°49.76'N, 71°17.72'W	12 July / 0800	39°48.11'N, 71°18.32'W
3	isopycnal	30°	12 July / 1300	39°49.67'N, 71°17.96'W	13 July / 0133	39°44.90'N, 71°18.00'W
4	isobaric	30°	13 July / 0211	39°47.57'N, 71°17.86'W	13 July / 0805	39°45.38'N, 71°17.40'W
2	isopycnal	15°	13 July / 1300	39°50.05'N, 71°17.86'W	14 July / 0245	39°47.86'N, 71°16.07'W
4	isopycnal	15°	5 August / 0346	44°34.16'N, 125°13.70'W	5 August / 1010	44°33.51'N, 125°13.49'W
4	isopycnal	15°	6 August / 2255	44°35.87'N, 125°00.12'W	6 August / 0527	44°35.69'N, 125°02.41'W

Table1. List of COOL float test deployments.

Design of the Float

The COOL float is constructed from a glass pipe 2.2 m long and with an outer diameter of 9.5 cm (Figure 1). The float consists of the glass pipe, electronics, a volume changer (VOCHA) located within the float, vanes and a compass, a pinger and either a compressee or drop weight.

The COOL float is based on the previously designed isopycnal f/h float (Rossby et al., 1994). Glass was used since it has a very small thermal expansion coefficient. Thus, the float will remain on the same density surface even if the temperature and salinity of the water changes but its density doesn't. If a water parcel is displaced vertically, it will either expand or compress due to the change in pressure and not change its potential density. Since the glass float is less compressible than seawater, it will not follow this water parcel. Therefore, a compressee is added to the float to match the float's compressibility to that of seawater (Figure 1).

The COOL float has a volume changer (VOCHA) in it to allow the float to follow a water parcel whose density is changing. However, in our short test deployments, we only used the VOCHA for calibration purposes (described later).

Eight vanes at a angle to the horizontal and a compass were added to the isopycnal f/h to make the COOL float. As water flows vertically past the float (Figure 1), the vanes will make the float rotate. Measuring the rotation rate with a compass inside the float will provide a measure of the *vertical* velocity past the float.

If the float is isobaric (that is, the float will remain at a constant pressure; it does not have a compressee), the vertical velocity past the float will be mainly due to the vertical velocity of internal waves. However, vanes on the isopycnal COOL float will make it respond to *diapycnal* velocities instead of *vertical* velocities. That is, the float will measure only the amount of water flowing past the float whose density is changing.

The float records temperature and pressure every 64 s and compass heading every 8 s during a 12 hr deployment (every 4 s during a 6 hr deployment).

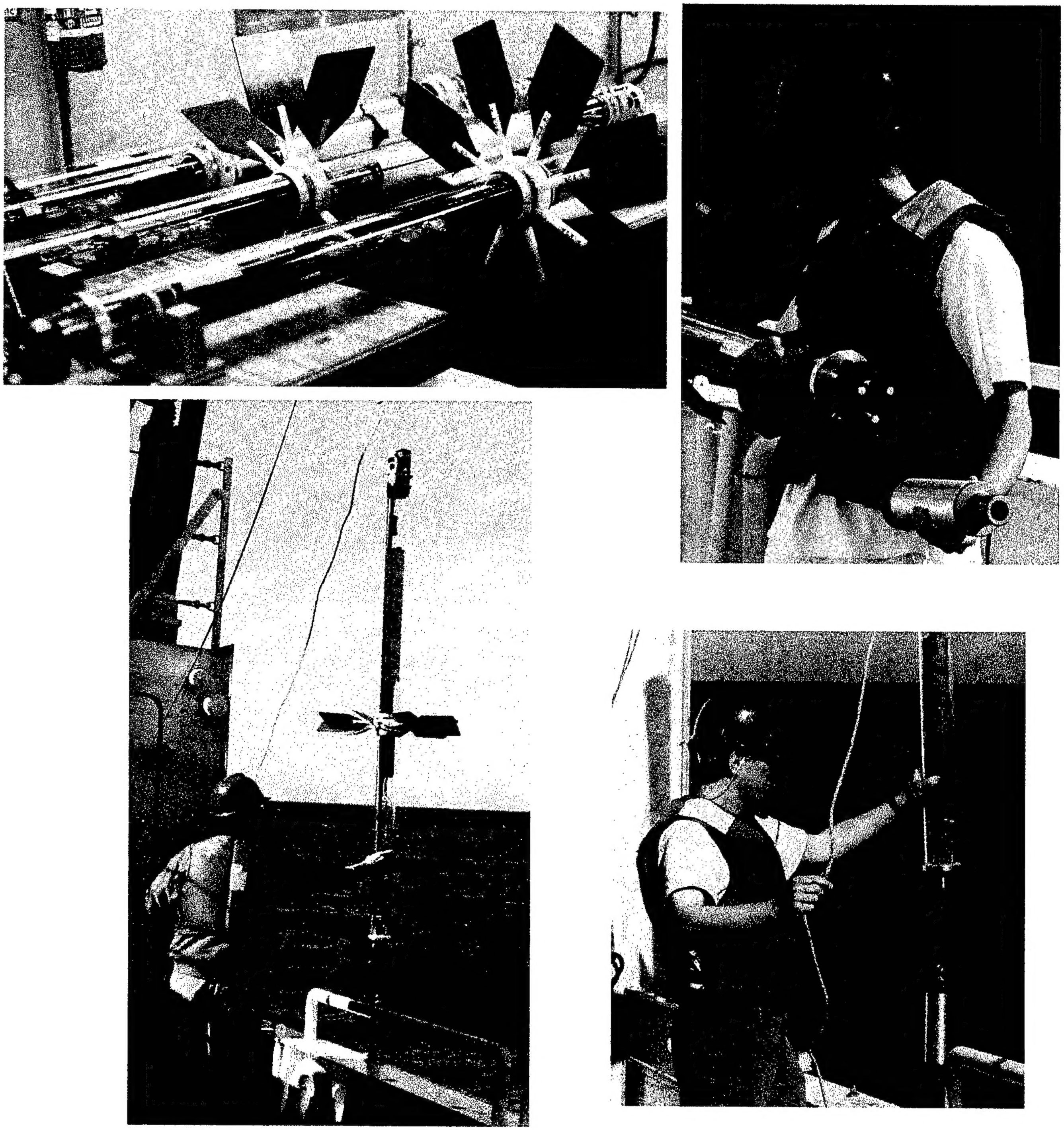


Figure 1.

Upper left panel: Two possible orientations of the vanes on the COOL float.

Upper right panel: The compressee (cylinder with piston) and 12 kHz pinger at bottom of the float.

Lower left panel: Deployment of a quasi-isobaric (no compressee) COOL float.

Lower right panel: Deployment of the isopycnal COOL float. The compressee is attached below the pinger and used as the drop weight.

Sample Deployment

In each deployment (nominally 6 or 12 hr), the float descends to the predetermined density surface. As it sinks, the float rotates rapidly as water flows past it (Figure 2). Then, the float remains on a density surface while being advected by the horizontal currents. This portion of the deployment will be referred to as the mission. If there is a vertical flow past the float, the float will rotate. To determine this vertical velocity, it is necessary to relate the speed of the float's rotation to a known vertical velocity. Thus, at the end of the float mission, the float makes five VOCHA moves which changes the float's density and makes it move vertically. The pressure and compass data allows us to determine the rotation rate — velocity calibration for the float (Figure 3). Near the end of the deployment, the float burns a release wire, drops a weight and returns to the surface for recovery.

The COOL float pinged at 12 kHz every 8 s and was tracked using the ship's hydrophone, PTR and LSR. We could detect the direct, the first bottom bounce and the first surface-bottom bounce arrivals out to a range of approximately 2 nm.

After the mision, a flasher, located at the top of the float, is activated for easy spotting at night. The float is recovered simply using a boat hook and attaching lines to the bail.

For this example of a COOL float deployment, it is evident that the float was on a density surface whose properties and dynamics were changing during its mission. CTD casts taken near the float show the variability of temperature and salinity in this region (Figure 2).

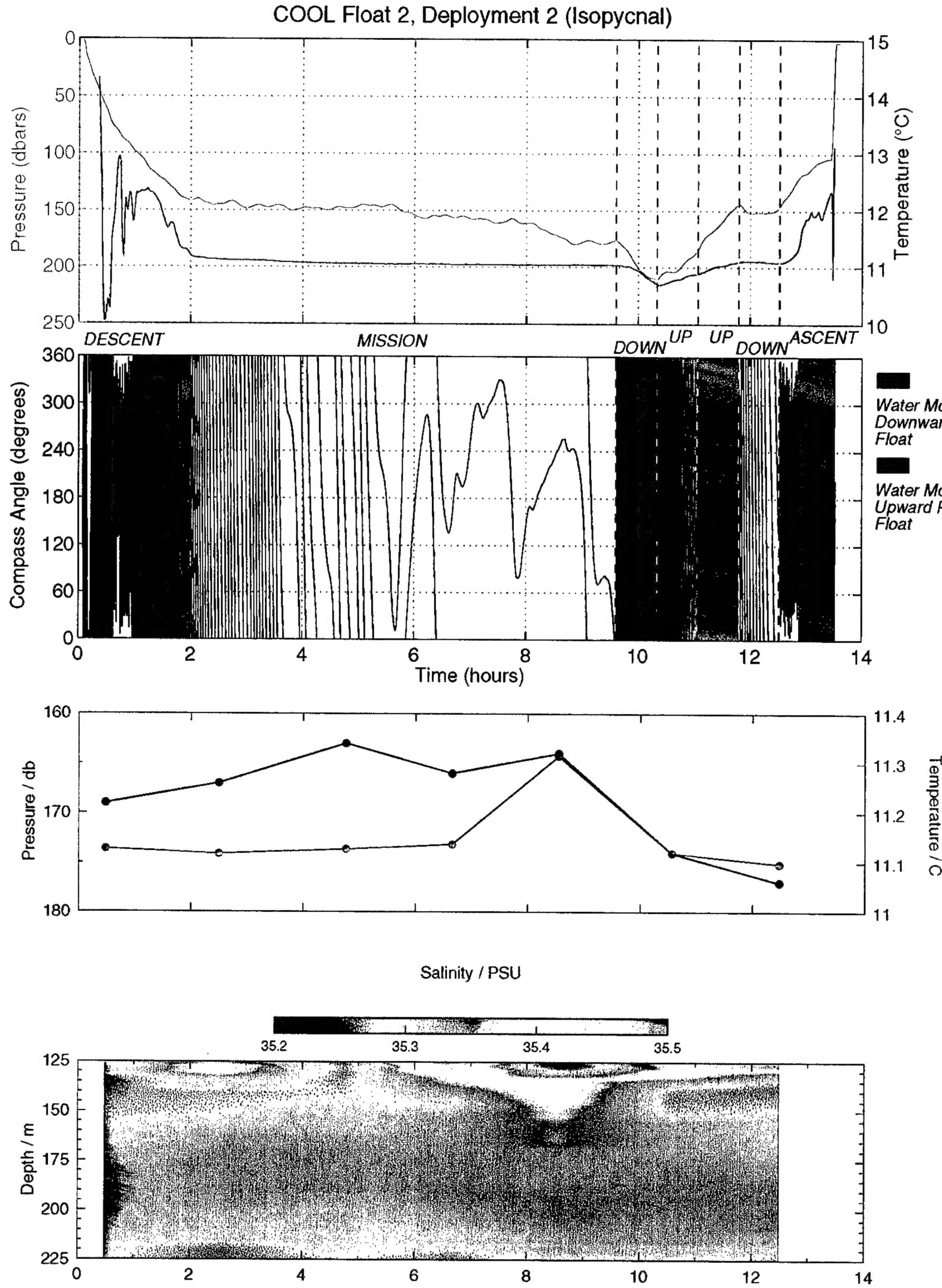


Figure 2.

Top two panels: Pressure, temperature and compass heading recorded by the COOL float for the total deployment.

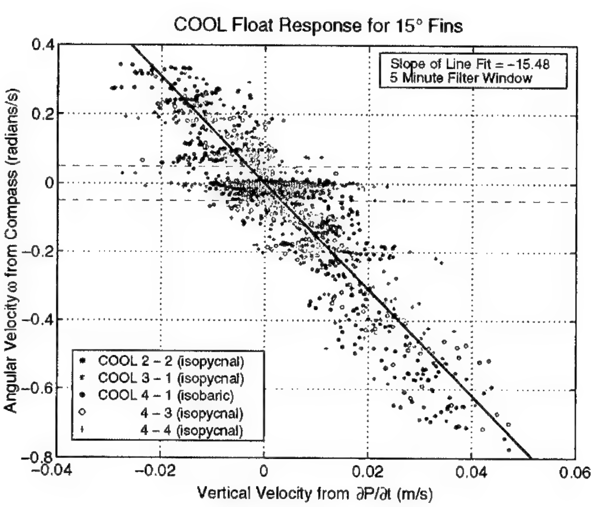
Bottom two panels: Pressure and temperature on the $\sigma_\theta = 27.0$ density surface and salinity over a limited depth range obtained from CTD casts made with a couple of miles of the float.

Calibration

Lowering and raising a prototype COOL float in a tank allowed us to determine the characteristics of the float and test various vane designs (Rajamony et al., 1996). Unfortunately, simulated vertical velocities less than 0.5 cm/s could not be obtained.

For each deployment of the COOL float, there are several portions of the deployment where the float rotation rate can be compared to its vertical velocity through the water column (Figure 2). There is the initial descent before the mission. After the mission, the volume changer (VOCHA) was moved five times (indicated by the vertical lines in the figures). The first four VOCHA moves change the float's volume by 4 cc, approximately equivalent to a change of 0.3 kg/m^3 in density. The last VOCHA move was a 7 cc change. Finally, the period after the release of the drop weight or compressee which brought the float to the surface provided additional data. We expect the rotation rate – vertical velocity calibration to be independent of which float is used and whether a compressee or drop weight is used. During our eight deployments, only three vane angles (15°, 30° and 90° to the horizon) were used. (With the vanes vertical, the float will only rotate due to a vorticity flow field on the horizontal scale of the float, i.e., on the order of 40 cm. Thus, the 90° vane angle makes the COOL float an isopycnal vorticity meter.)

There is a very good correlation with rotation rate of the COOL float and its change in pressure (Figure 3). As expected, the float's rotational response is independent of type of float. Also, for a vane angle closer to the horizon, the float rotates faster for a given vertical velocity. The scatter in Figure 3 is mainly due to internal wave contamination in the pressure signal.



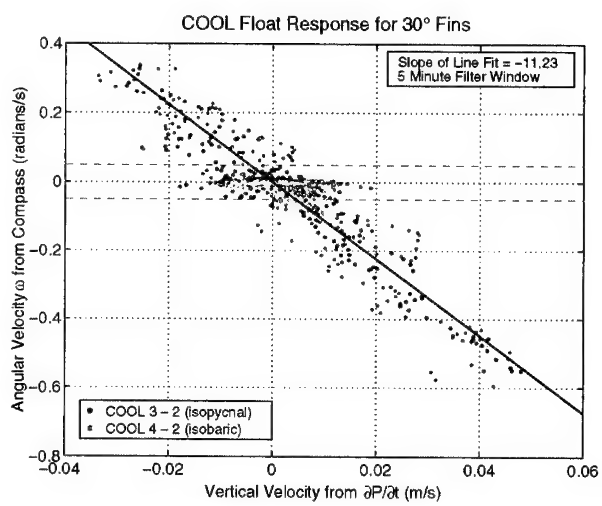


Figure 3

Rotational response of COOL float to measured pressure change for all floats and deployments. Dashed lines show the range of data collected while the float was either on an isopycnal or isobaric surface. This data was not used in the linear regression calculation. The slope of the regression supplies the calibration of rotation to vertical velocity for a particular vane design and is used in the further analysis.

Preliminary Results

Eight short deployments of the COOL float have been undertaken (Figures 4–11). A variety of vane angles and either as an isobaric or isopycnal float were examined (Table 1). For each deployment, the vertical velocity of the (isobaric or isopycnal) float during its mission can be determined from its pressure record (Figures 12–19). That is, the vertical velocity of the float is $(-\partial P/\partial t)$. An estimate of the vertical velocity of the water past the float can be made from the temperature data. The period of VOCHA moves at the end of the float mission allows the mean temperature gradient (i.e., $(\overline{\partial T/\partial P})$) to be estimated. The vertical velocity of the water past the float is $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$. Finally, for all float mission except the first deployment of COOL float #2 which had its vanes vertical, the vertical velocity of water past the float can be determined from its rotation rate ω and the calibration for the vane angle (Figure 3).

The analysis of the data from these test deployments are underway. However, preliminary results from the missions of three deployments of the isopycnal COOL floats are presented below.

The first deployment of the three to be discussed was off the continental shelf south of Rhode Island (second deployment of COOL float #2); the second deployment to be discussed is one of the float deployments made off of Oregon where upwelling might be occurring (fourth deployment of COOL float #4). The third deployment is the deployment of the COOL float with the vanes vertical (first deployment pf COOL float #2); that is, an isopycnal vorticity meter float.

For the first example, the COOL float must be moving from one water mass to another during its mission (Figures 2, 9 and 17). The float mission can be divided into two parts. For the first half, the float is at a constant pressure but seeing a decrease in water temperature and rotating due to a vertical velocity past it (Figure 20). In the second half of the mission, the float does not seeing a temperature change or rotating; however, its pressure is increasing. As expected, the vertical velocity estimated from pressure is dominated by internal waves. The large variability of the vertical velocity based in the temperature signal is due to bit noise in the temperature data. Smoothing the data with a Butterworth filter having a half-power point at 10 min reduces the variability (compare Figure 20 with Figure 17).

During the deployment off of Oregon, winds conditions were favourable for upwelling. During the short mission of the COOL float, it appears that the float is being carried upwards with the upwelled water (Figure 19). That is, the isopycnals are surfacing. However, the temperature of the water tagged by the isopycnal float decreased. Thus, there appears to be a diapycnal velocity. The COOL float measured a very weak vertical velocity (Note: The vertical velocity has been amplified by a factor of 10 in Figure 21.) The compass heading data (Figure 11) leads us to believe that there is a mean diapycnal velocity at the beginning of the mission. However, care must be taken in interpreting such a short time series.

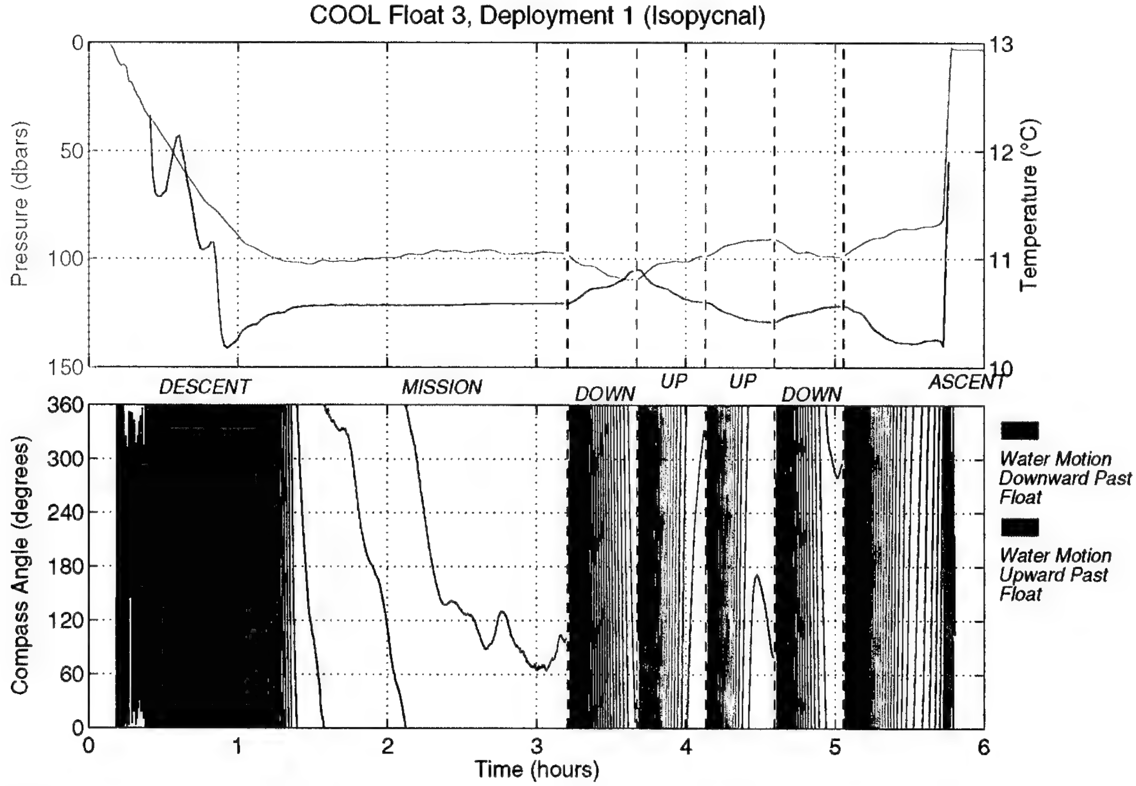


Figure 4. First deployment of COOL float #3 (isopycnal and 15° vanes).

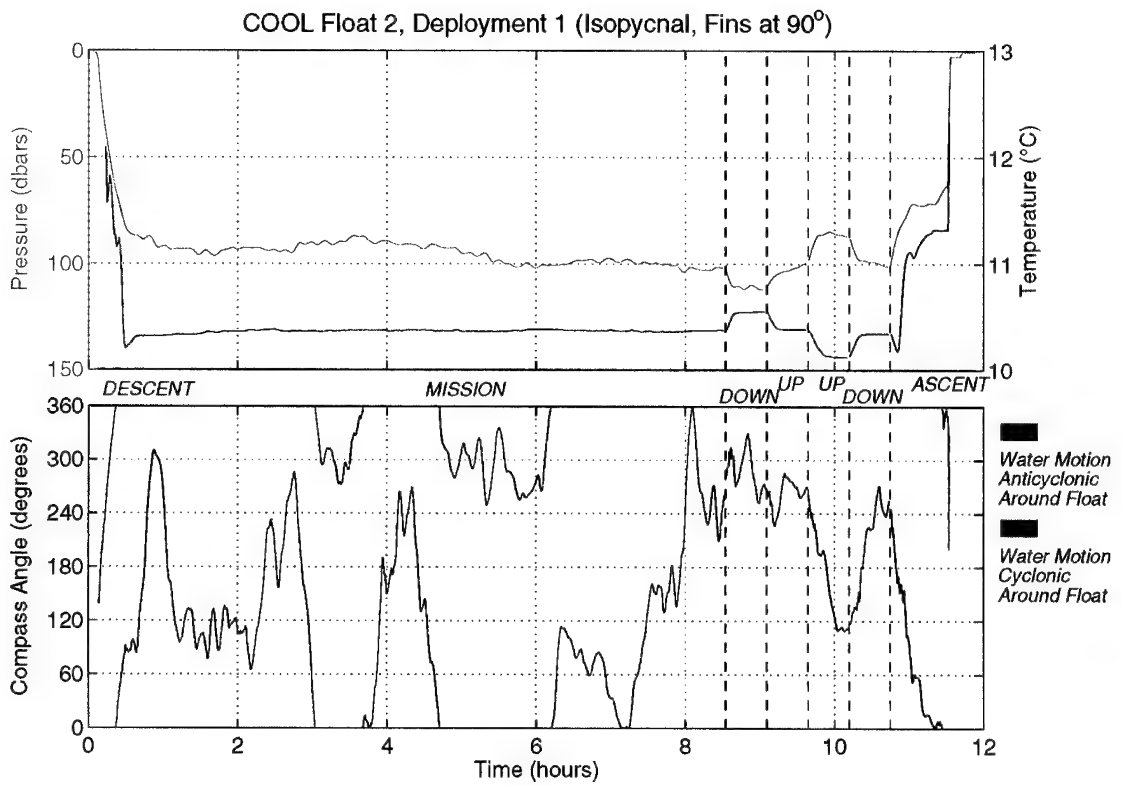


Figure 5. First deployment of COOL float #2 (isopycnal and 90° vanes).

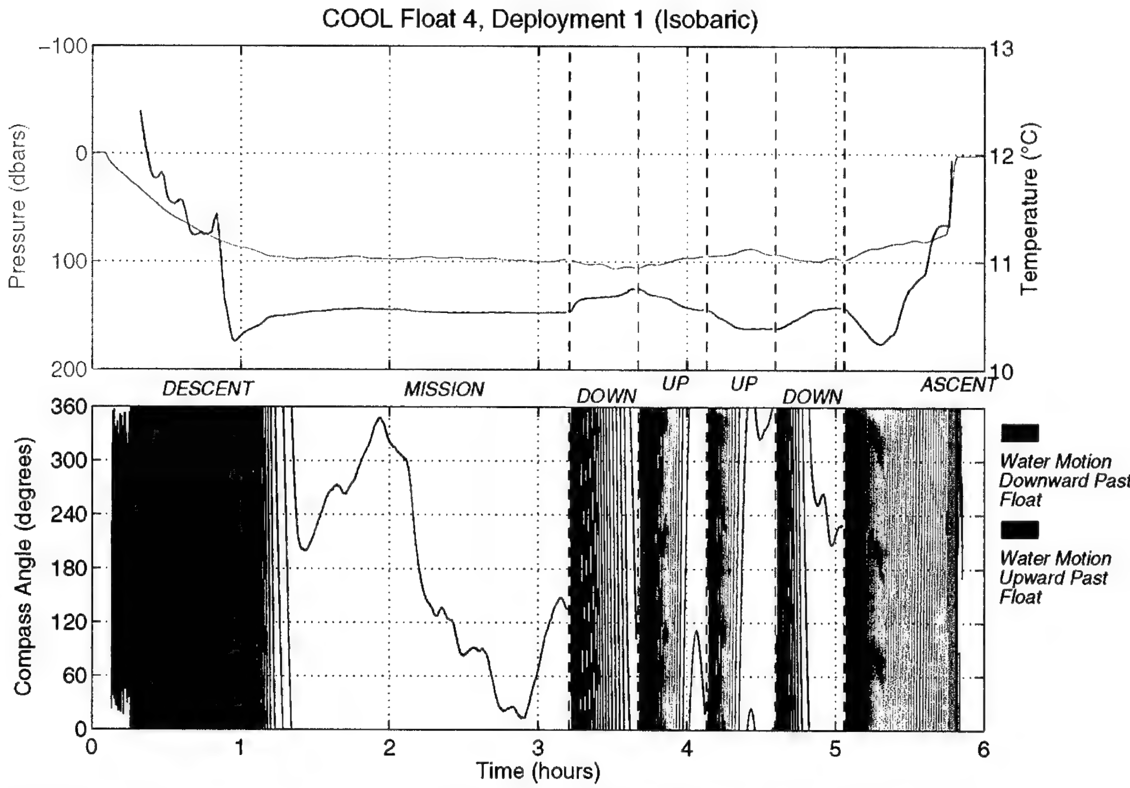


Figure 6. First deployment of COOL float #4 (isobaric and 15° vanes).

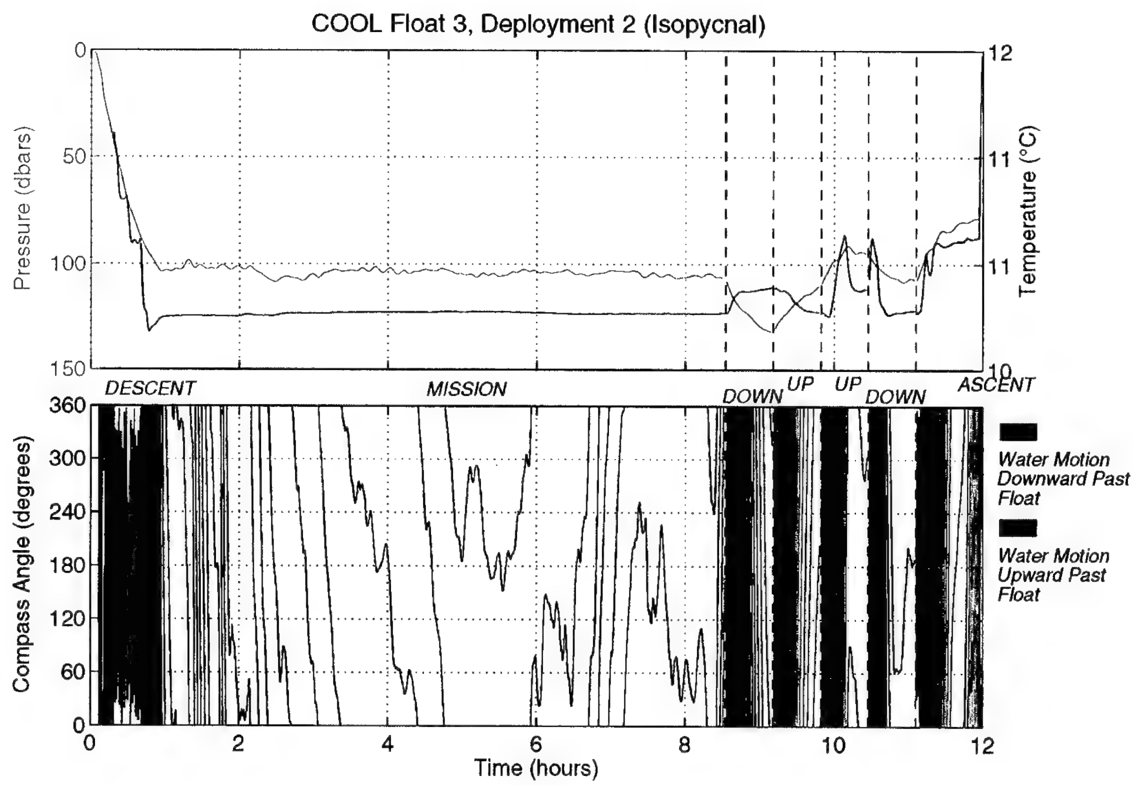


Figure 7. Second deployment of COOL float #3 (isopycnal and 30° vanes).

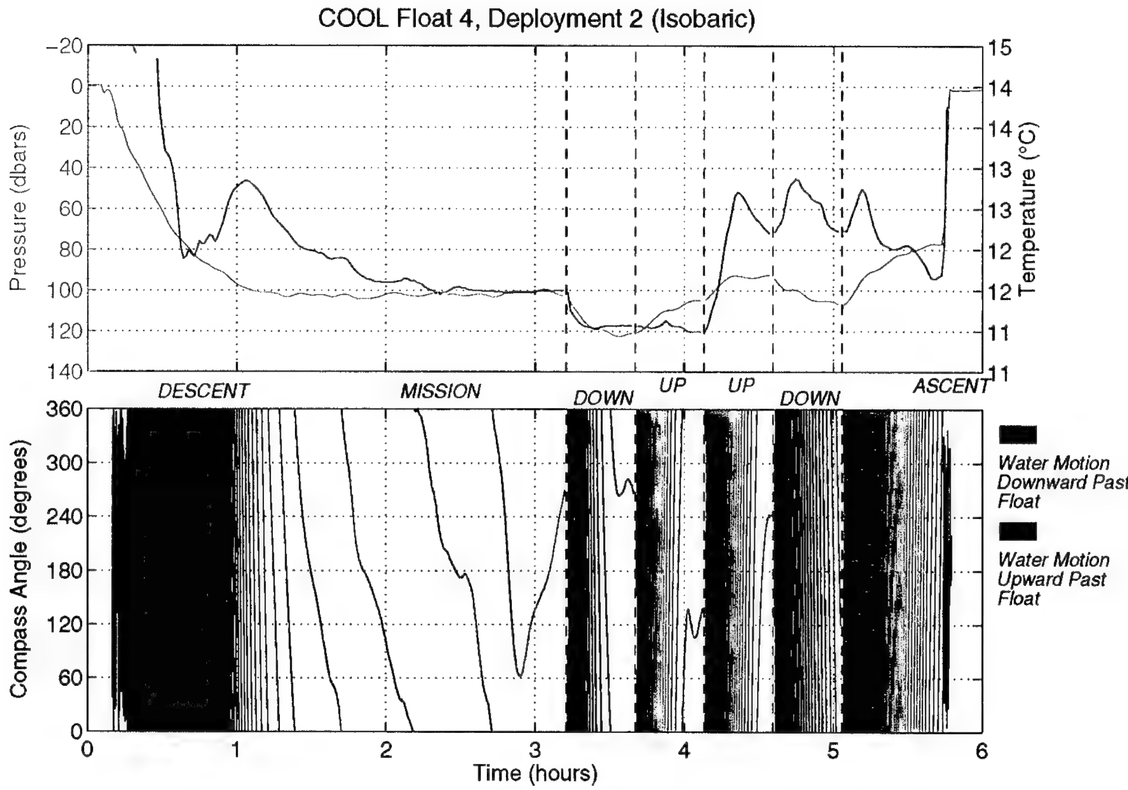


Figure 8. Second deployment of COOL float #4 (isobaric and 30° vanes).

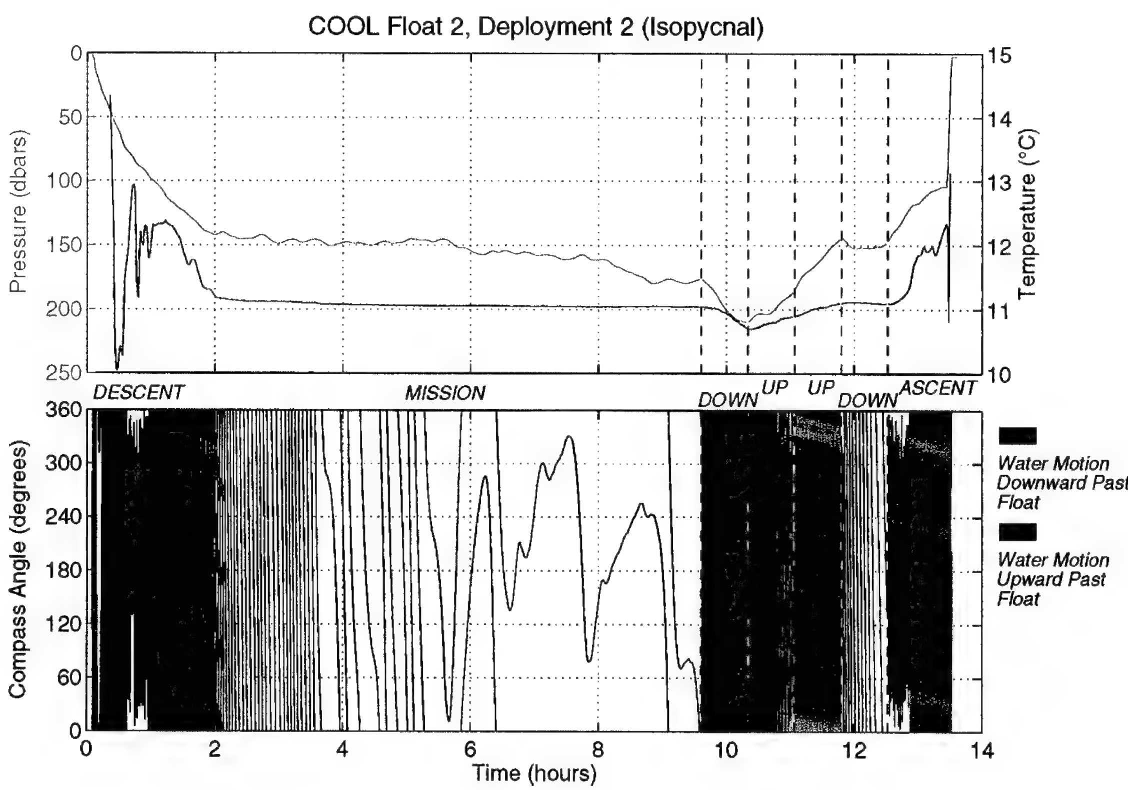


Figure 9. Second deployment of COOL float #2 (isopycnal and 15° vanes).

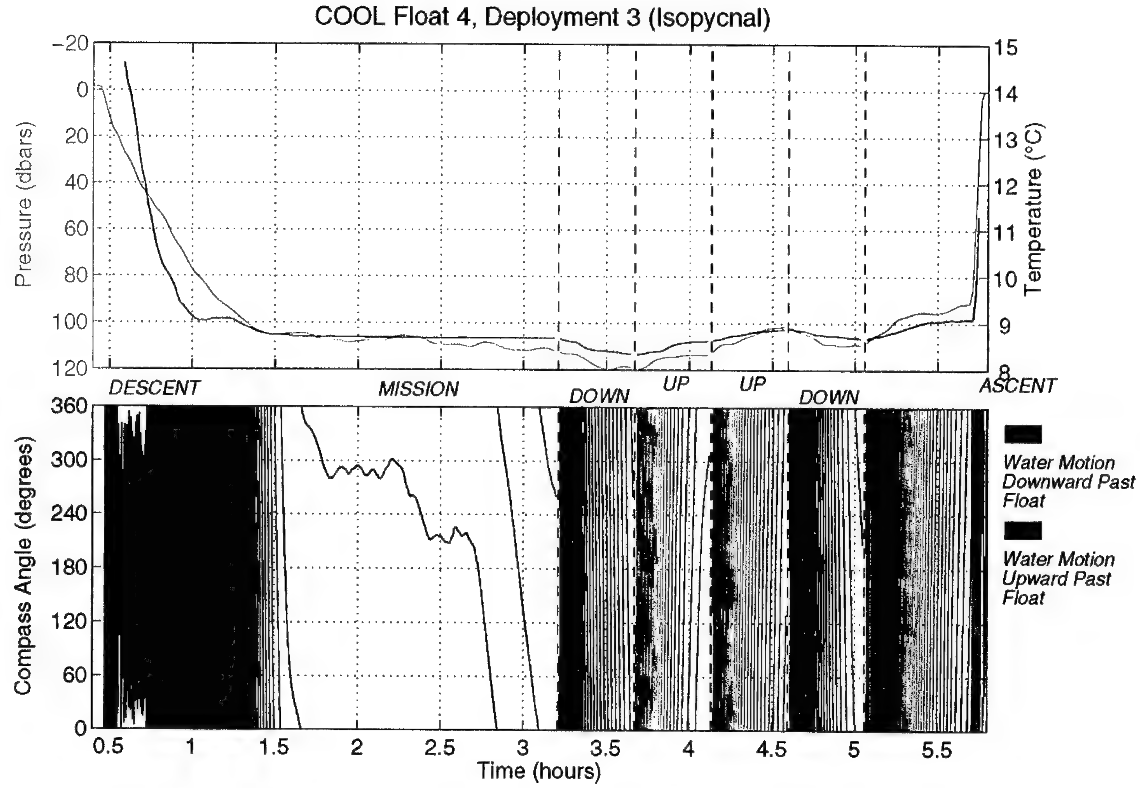


Figure 10. Third deployment of COOL float #4 (isopycnal and 15° vanes).

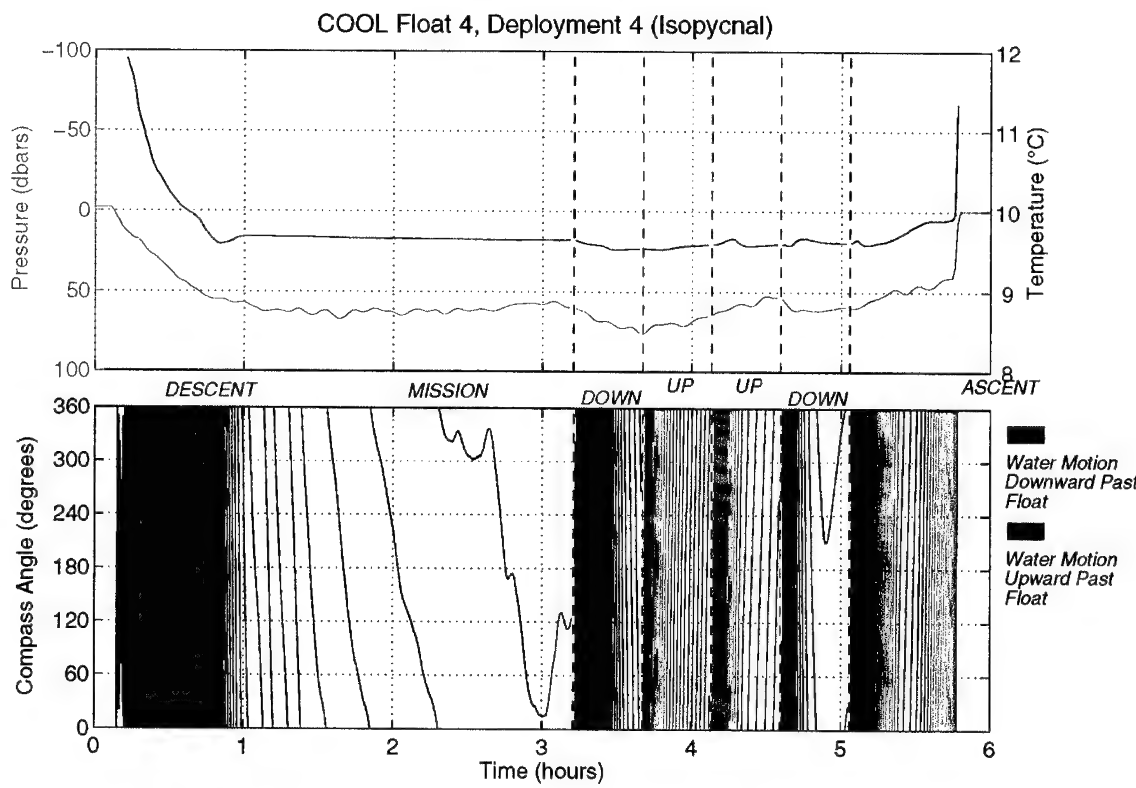


Figure 11. Fourth deployment of COOL float #4 (isopycnal and 15° vanes).

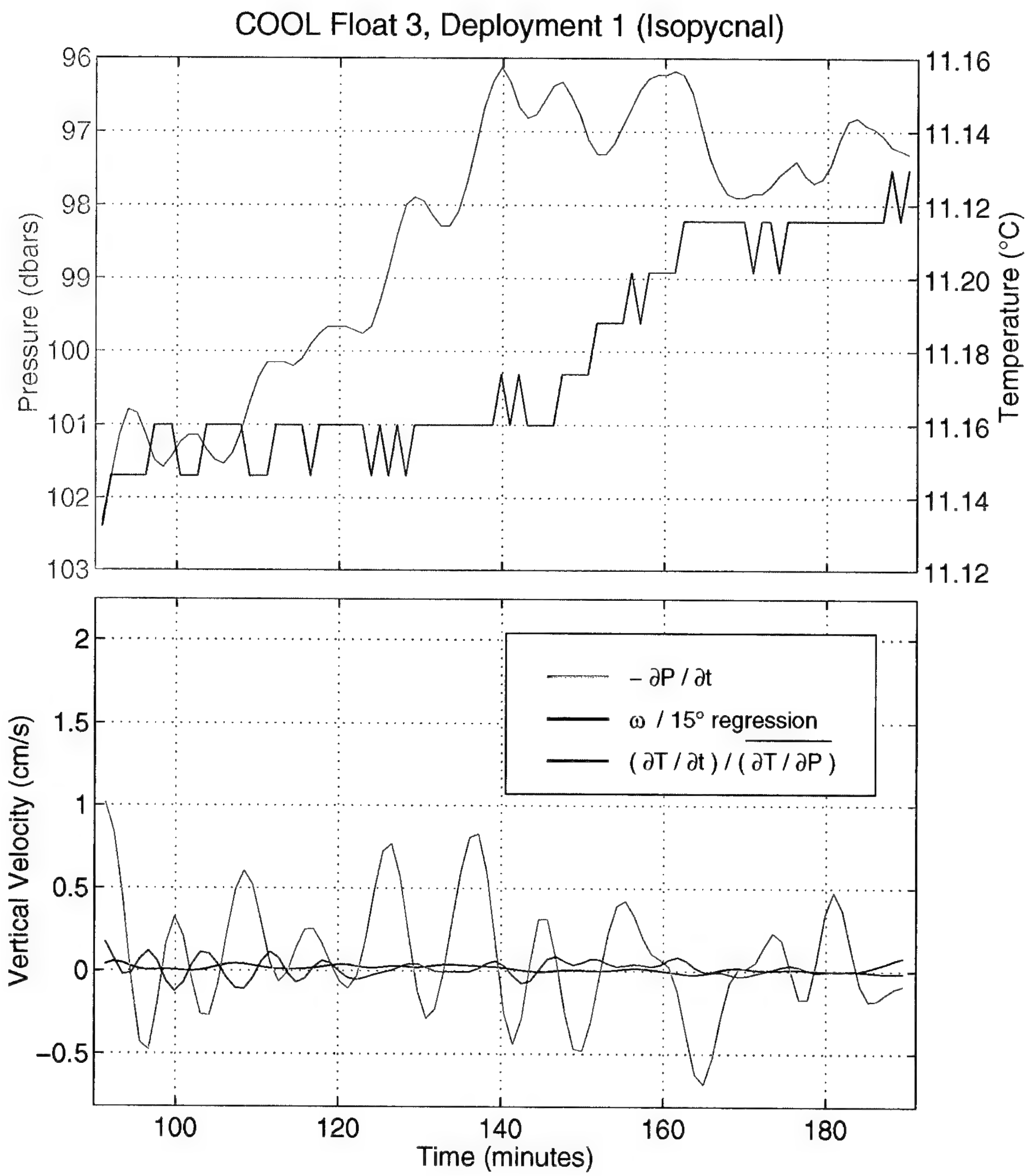


Figure 12

Top panel: Temperature and pressure recorded by the COOL float (first deployment of #3) during its mission.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

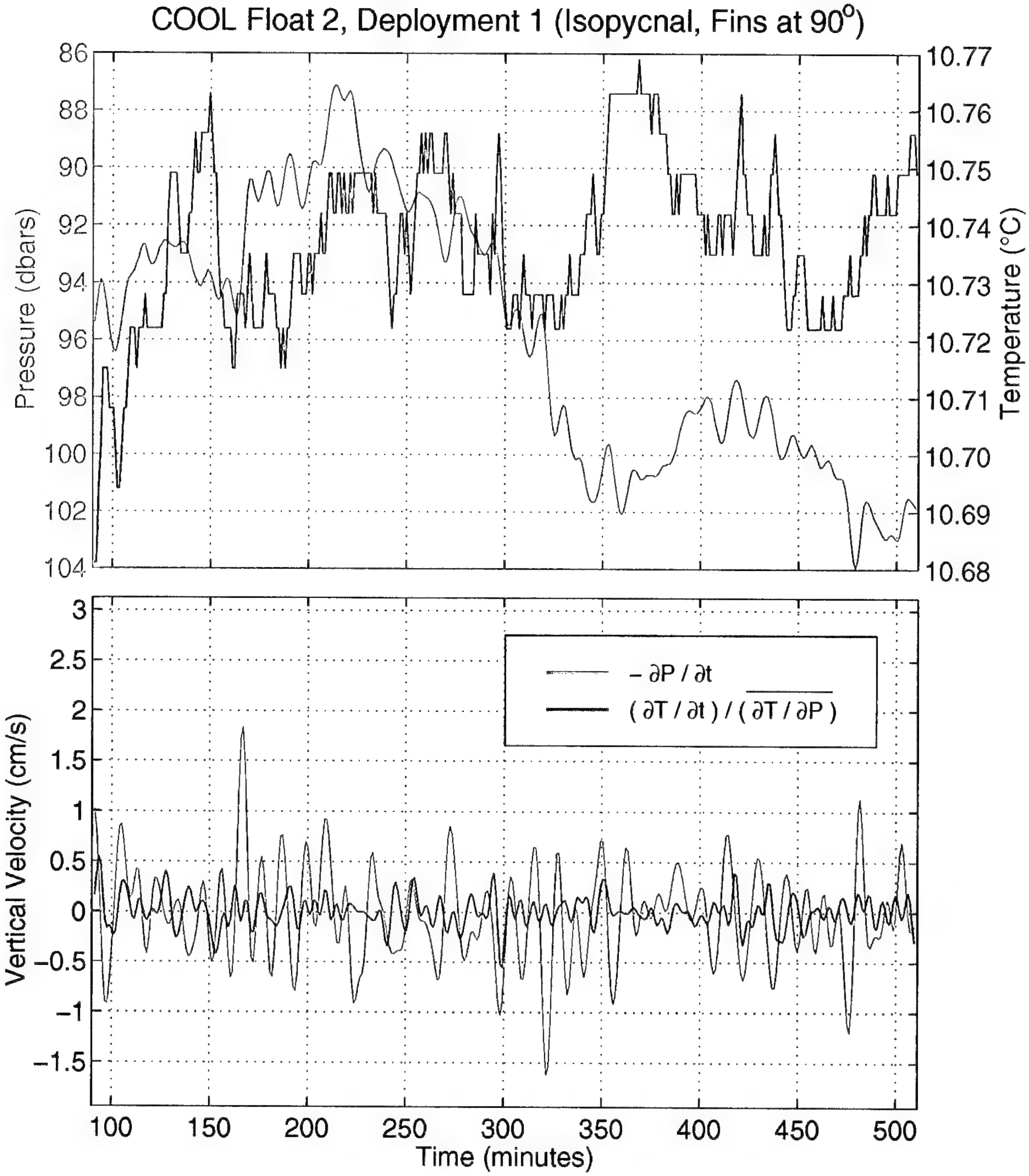


Figure 13

Top panel: Temperature and pressure recorded by the COOL float (first deployment of #2) during its mission.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

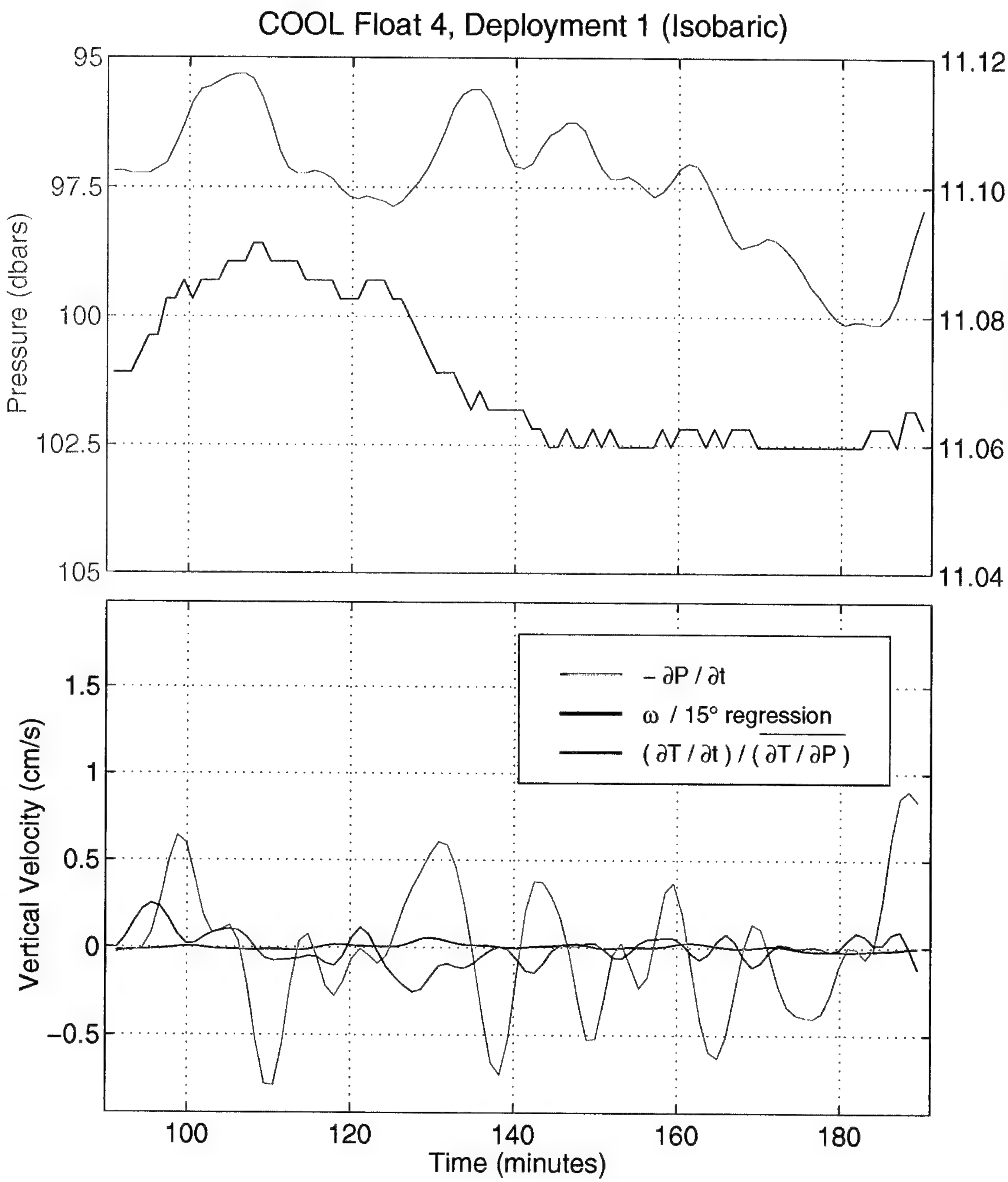


Figure 14

Top panel: Temperature and pressure recorded by the COOL float (first deployment of #4) during its mission.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

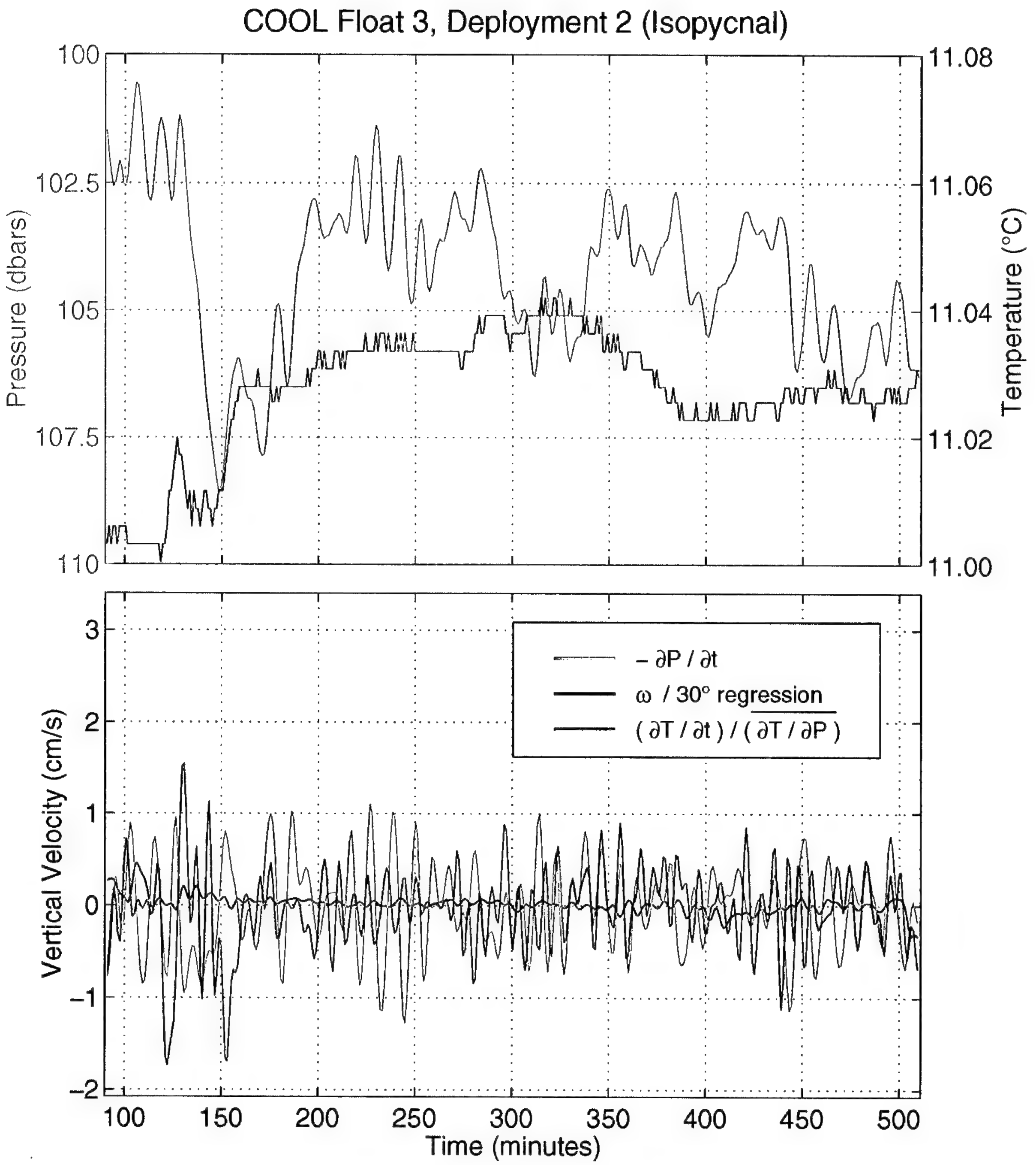


Figure 15

Top panel: Temperature and pressure recorded by the COOL float (second deployment of #3) during its mission.

Bottom panel: Vertical velocity of the float $(-\overline{\partial P/\partial t})$ and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

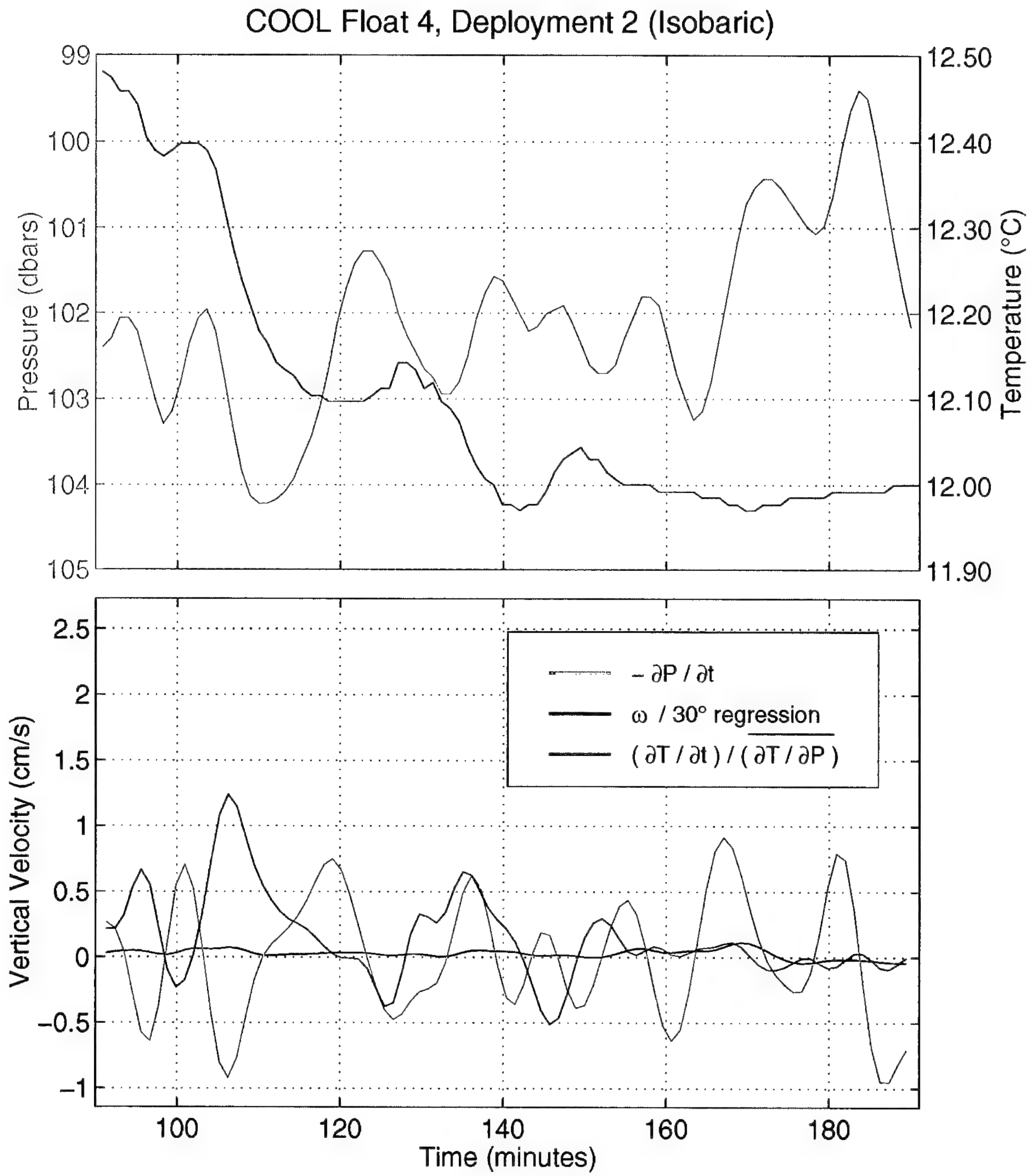


Figure 16

Top panel: Temperature and pressure recorded by the COOL float (second deployment of #4) during its mission.

Bottom panel: Vertical velocity of the float $(-\partial P/\partial t)$ and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

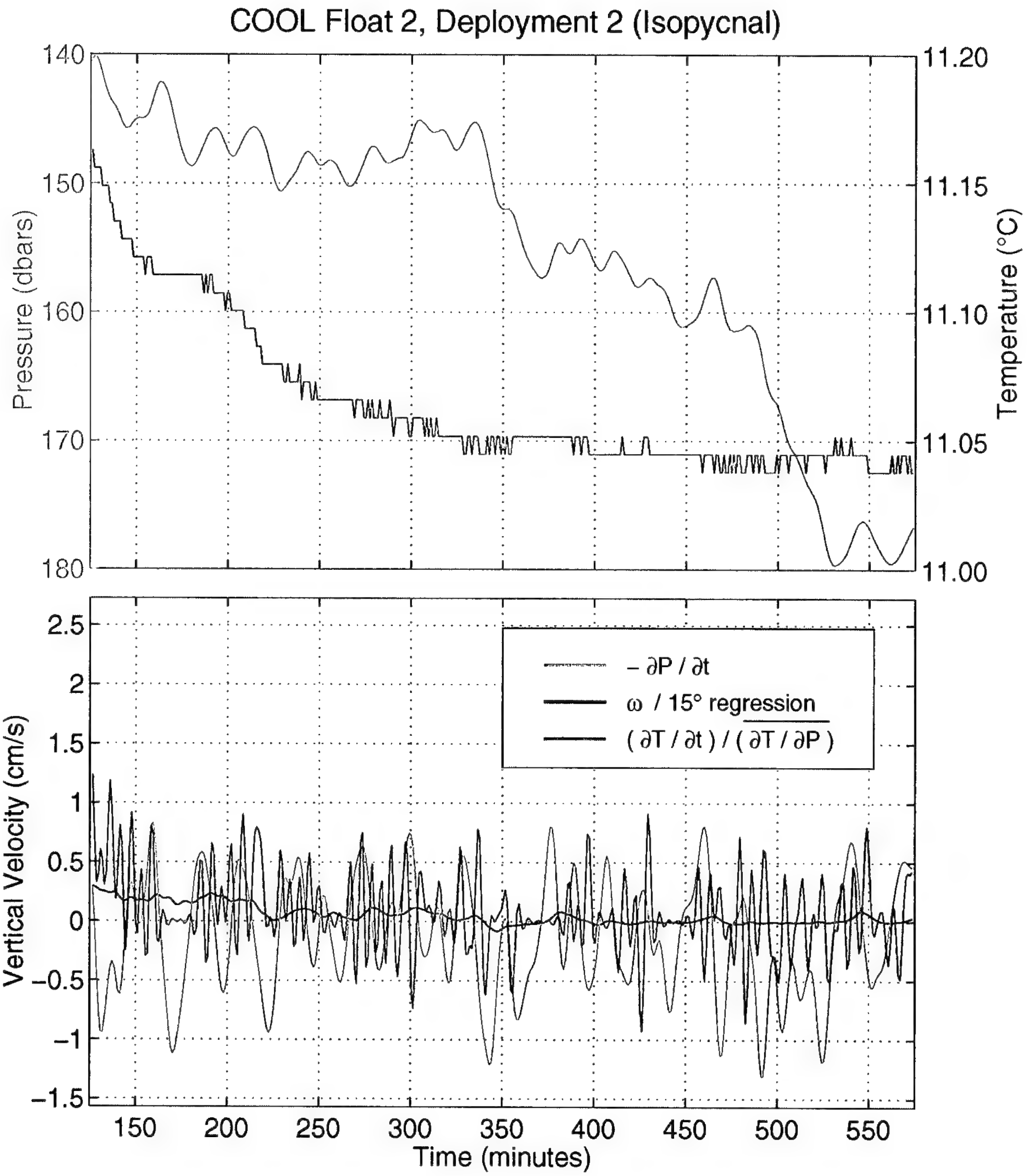


Figure 17

Top panel: Temperature and pressure recorded by the COOL float (second deployment of #2) during its mission.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

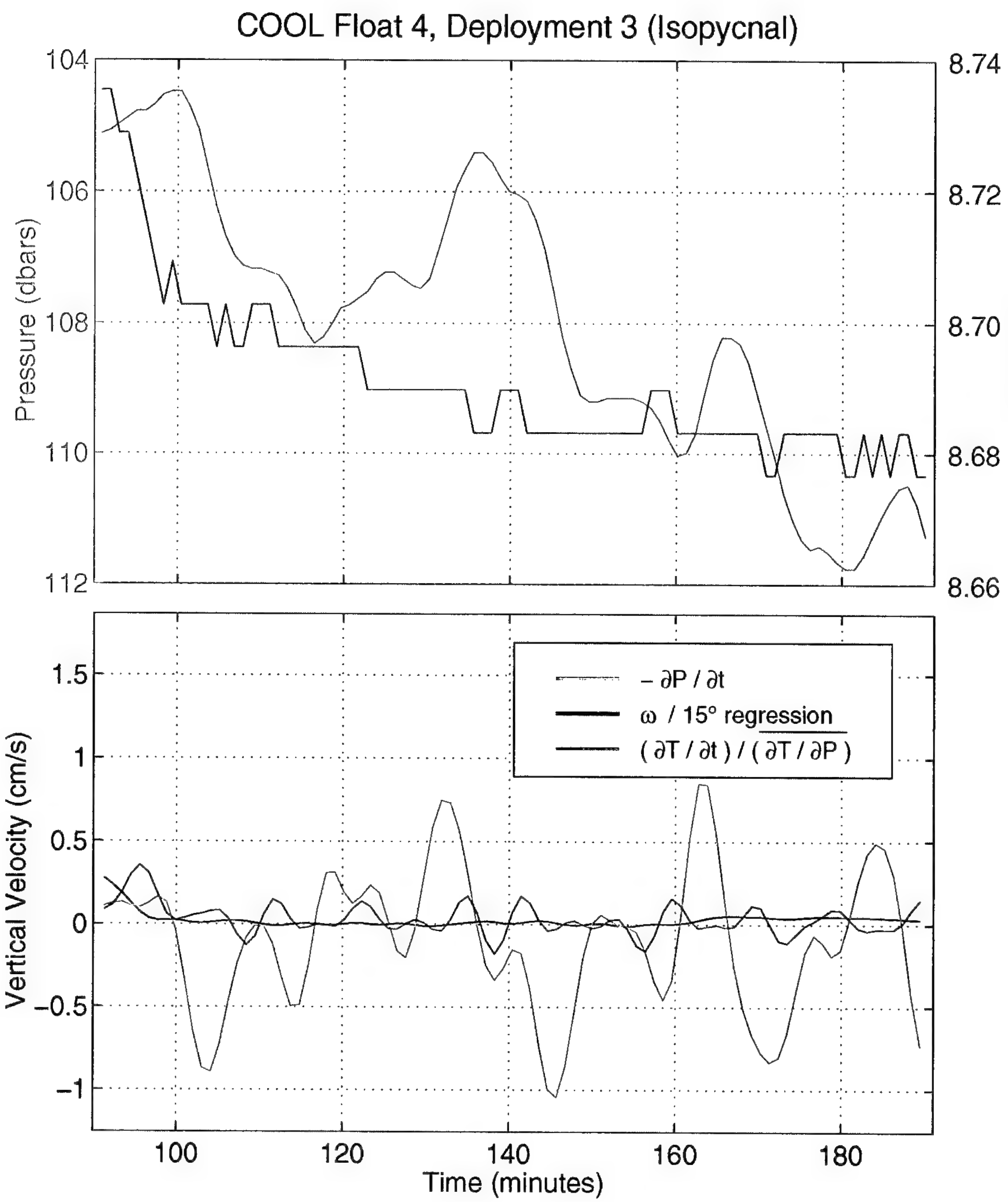


Figure 18

Top panel: Temperature and pressure recorded by the COOL float (third deployment of #4) during its mission.

Bottom panel: Vertical velocity of the float $(-\partial P/\partial t)$ and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

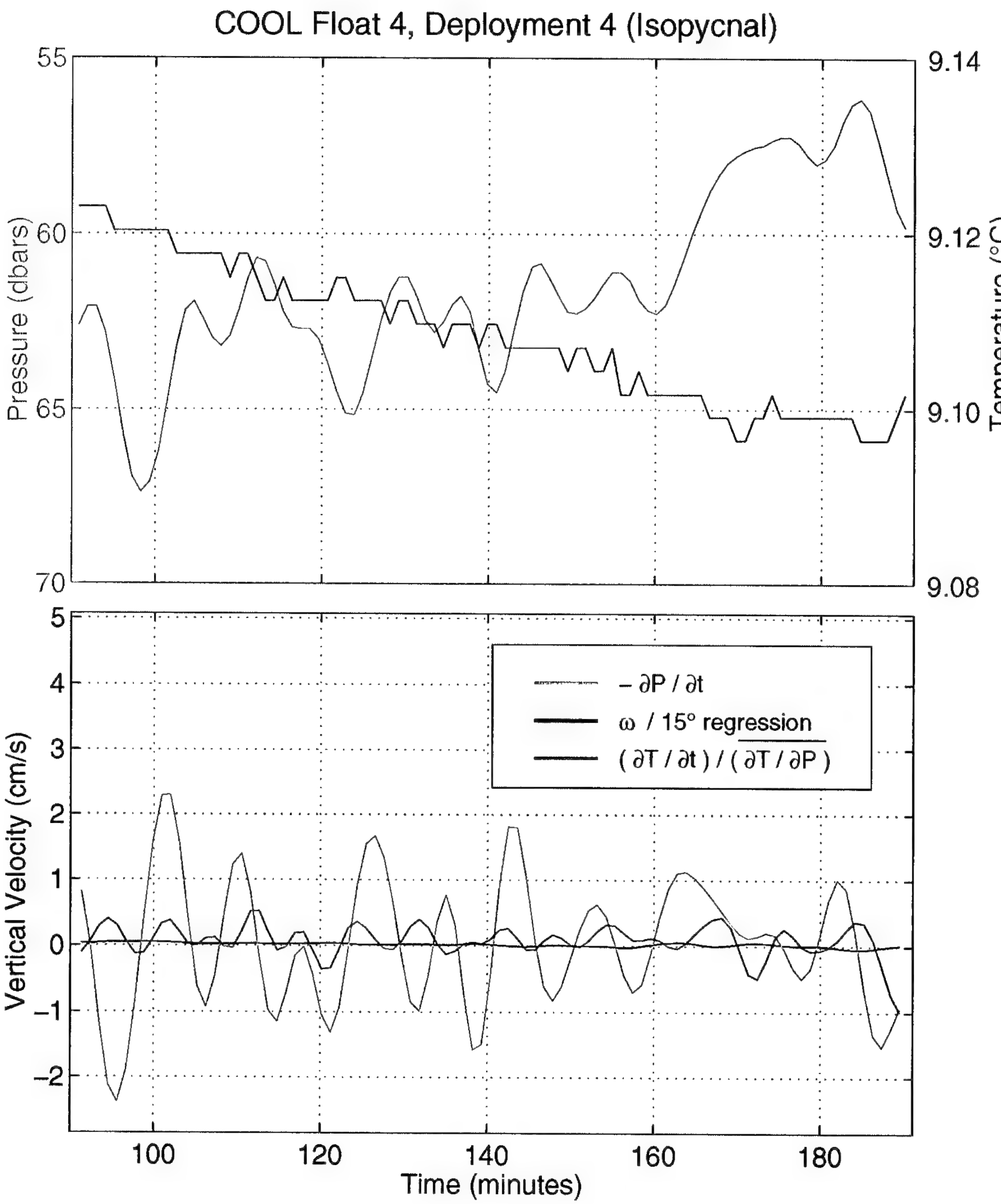


Figure 19

Top panel: Temperature and pressure recorded by the COOL float (fourth deployment of #4) during its mission.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

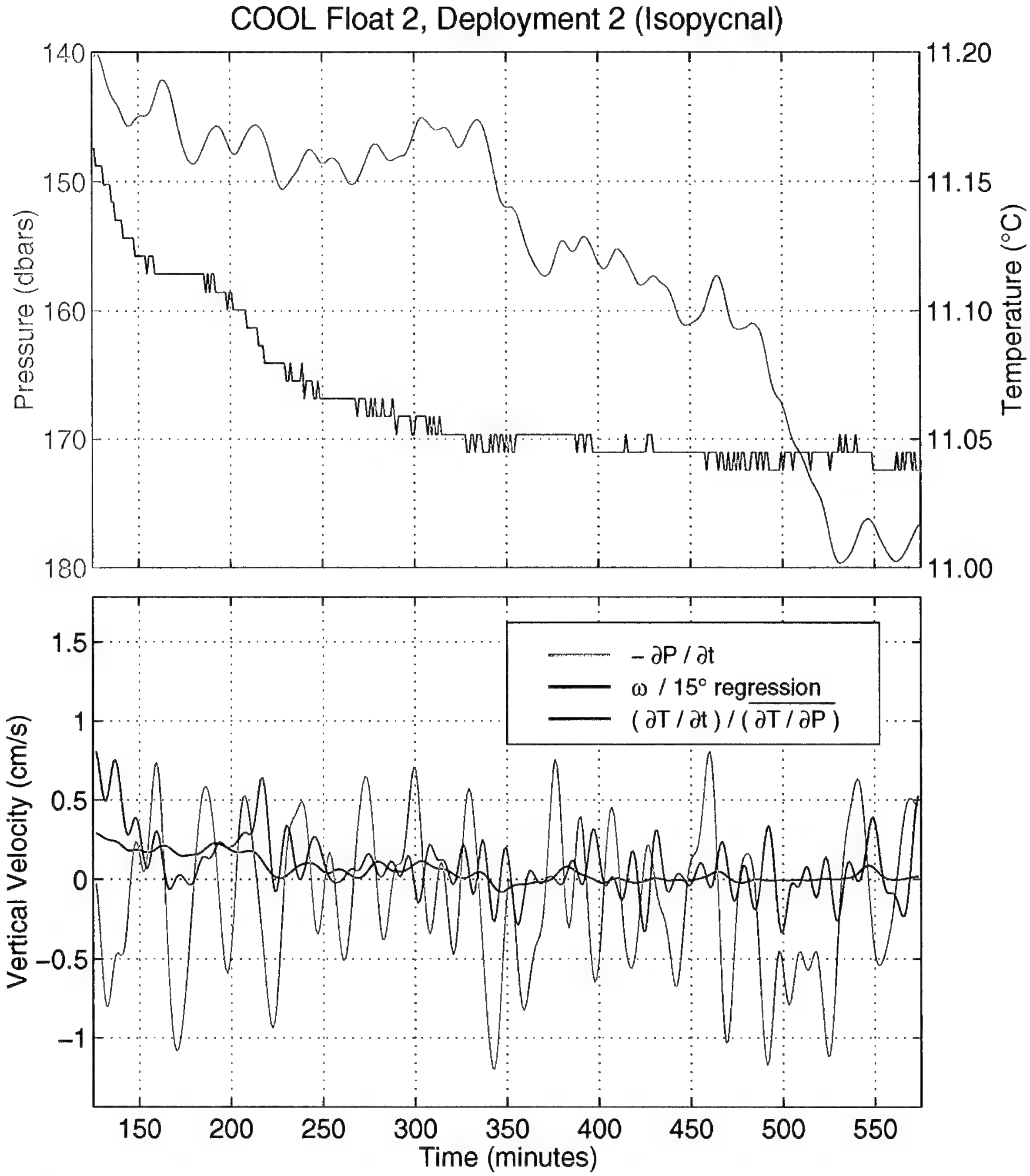


Figure 20.

Top panel: Temperature and pressure recorded by the COOL float while on an isopycnal surface.

Bottom panel: Vertical velocity of the float ($-\partial P/\partial t$) and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω. Data has been smoothed with a Butterworth filter having a half-power point at 10 min.

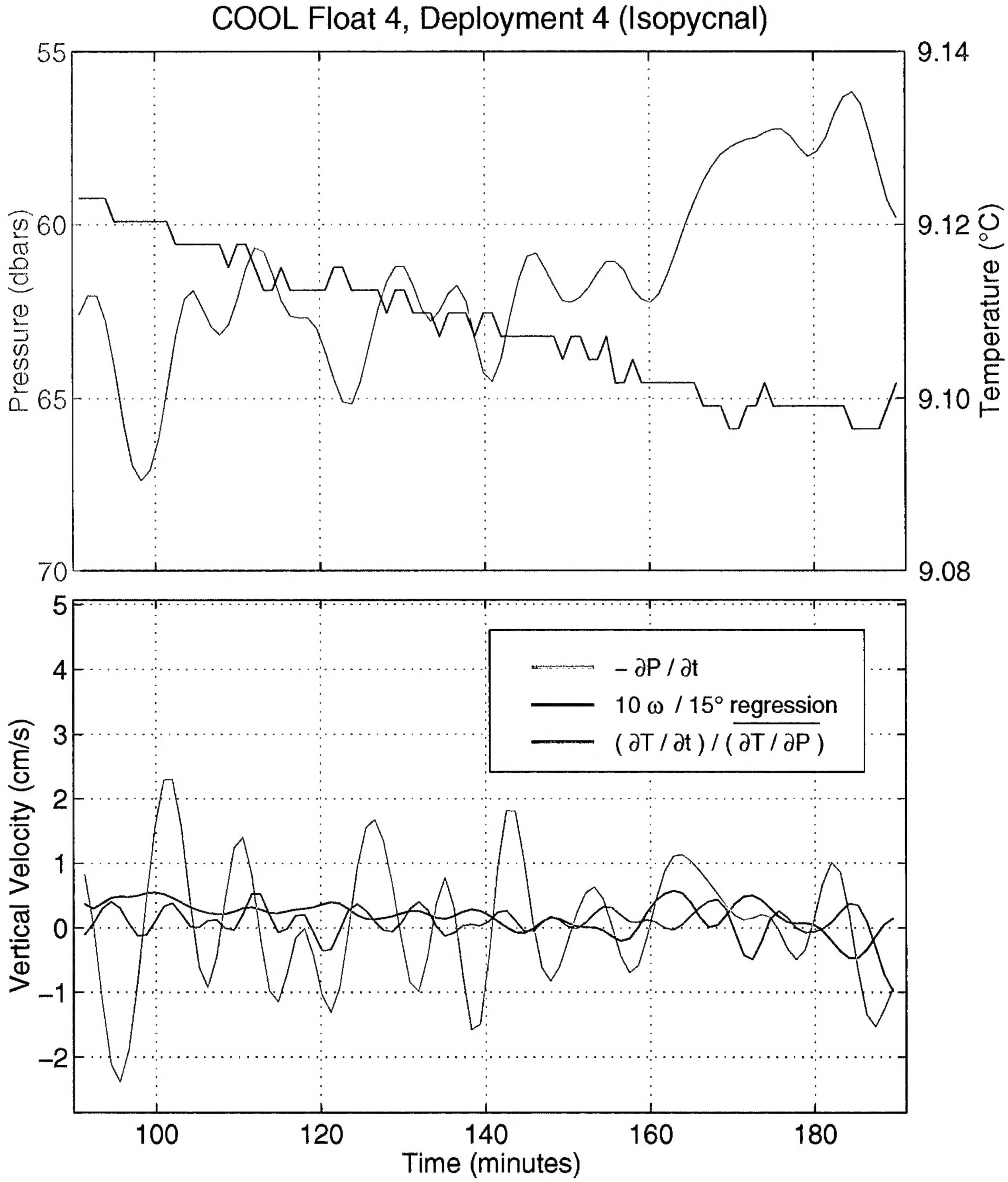


Figure 21

Top panel: Temperature and pressure recorded by the COOL float while on an isopycnal surface.

Bottom panel: Vertical velocity of the float $(-\partial P/\partial t)$ and vertical velocity past the float based on temperature change $[(\partial T/\partial t)/(\overline{\partial T/\partial P})]$ and rotation of the float ω (multiplied by a factor of 10). Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

For one deployment, we made the isopycnal COOL float a small-scale vorticity meter. The temperature and pressure data could still be used to estimate vertical velocities during the mission (Figure 13). However, the vanes on the float would only rotate the COOL float if there was a horizontal shear in velocity present. The small-scale vorticity based on the angular rotation rate of the float can be compared to the planetary vorticity (Figure 22). There is large small-scale high-frequency vorticity present (Figure 22) while the net vorticity is very small (see compass heading data in Figure 5).

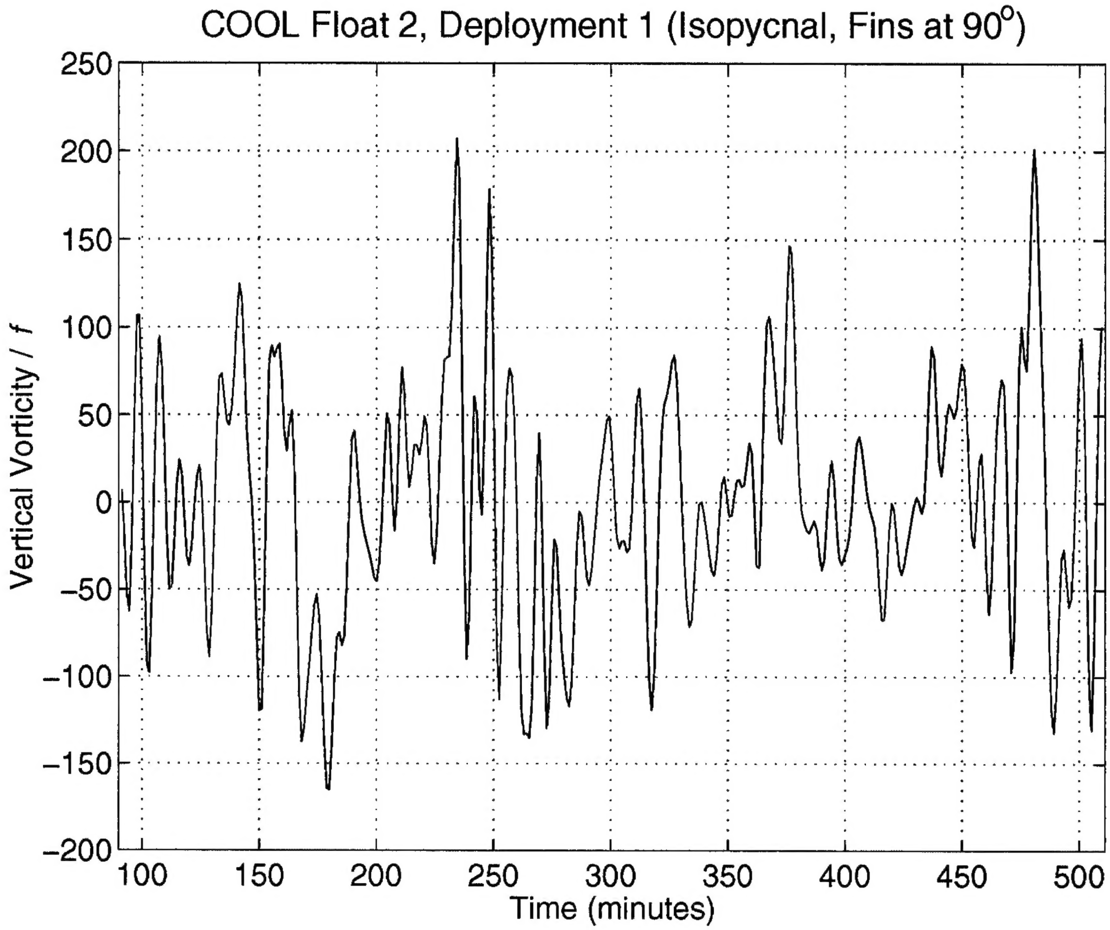


Figure 22 Relative vorticity, based on the rotation rate of the COOL float, scaled by the local Coriolis parameter. Data has been smoothed with a Butterworth filter having a half-power point at 5 min.

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Rossby, T., J. Fontaine and E.C. Carter, Jr. 1994: The f/h float — measuring stretching vorticity directly, *Deep-Sea Res.*, **41**, 975-992.

Rajamony, J., S. Peterson, J. Fontaine, D. Hebert, T. Rossby and M. Prater. 1996: Vane Design for the COastal Ocean Lagrangian (COOL) Float, Graduate School of Oceanography Technical Report 96-8, University of Rhode Island, 24pp.

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The goal of this project is to develop a truly three-dimensional Lagrangian follower of water parcels for the coastal ocean. This COastal Ocean Lagrangian (COOL) float is based on an isopycnal float which would follow fluid parcels on a constant density surface. However, in the coastal ocean, there is significant mixing occurring such that a water parcel can change its density over a relatively short time. To account for this effect, we have designed a float which measures vertical (diapycnal, if the float is isopycnal) velocity past it. The COOL float has the capability to change its volume, hence its density, and follow the water parcel.

We have completed two short cruises to test the COOL float. The first one (July 1997) was just off the continental shelf south of Rhode Island. We did six deployments of the COOL float using a variety of vane angles and either as an isobaric or isopycnal float. During August 1997, we completed two deployments of an isopycnal COOL float off the coast of Oregon, in an attempt to look at water that might be upwelling there.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL